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Structural Design Considerations for Cold Thrust Augmentation Fighter Concepts

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STRUCTURAL DESIGN CONSIDERATIONS FOR COLD THRUST AUGMENTATION FIGHTER CONCEPTS

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FOREWARD

An investigation of the structural requirements for the application of the Cold Thrust Augmentation (CTA) principle to V/STOL fighter aircraft was performed by the Structures Division of the Air Force Flight Dynamics Laboratory. This investigation was performed in support of the CTA Fighter Design Study performed by the Prototype Division of the Air Force Flight Dynamics Laboratory. The results of the investigation have been used to identify and define several structural design guidelines which will help to assure efficient and successful incorporation of this type of propulsion system in any future CTA design concept study programs.

This Technical Memorandum has been reviewed and is approved.

KEITH I. COLLIER
Chief, Advanced Structures Branch
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I. SUMMARY

The purpose of this report is to document progress to date on the structural design effort conducted by the Preliminary Design Group, Advanced Structures Branch, Structures Division, in support of a Prototype Division V/STOL Aircraft. The investigation of the use of the Cold Thrust Augmentation (CTA) principle on a V/STOL aircraft was limited to two Prototype Division generated configurations. One configuration involved a CTA pod located at the wing tip while the second configuration was a fuselage mounted CTA system.

A different aspect of each configuration was investigated. The investigation of the wing tip mounted CTA pod consisted of a limited loads and design analysis on the CTA pod, wing and tail surfaces since these were considered to be critical areas of this configuration. The critical area of the fuselage mounted CTA system was considered to be the duct system needed for the hyper-mixing nozzles. Therefore, this duct system was investigated.

As a result of the analysis performed on the wing tip mounted CTA pod, it was determined that the wing could not support the loads induced by the combination of the pod, gear and tail surfaces and still maintain the volume needed for the ducting system. As a solution to these problems and several other problems outlined in the report, the pod was relocated inboard.

The fuselage mounted CTA configuration had several peculiar problems.

These problems included high operating temperatures combined with internal pressures and mass flow requirements which had to be satisfied within the mold lines of the aircraft. By manipulating the shape and design of the ducts the concept was found to be feasible from a volume and materials standpoint but very critical from a weight standpoint.

Both of these concepts have not yet been completely investigated. Due to a redirection of the work efforts of the V/STOL Group of the Prototype Division, the work has been temporarily halted.

II. INTRODUCTION

The purpose of this report is to describe and document the structural preliminary design activity performed in support of the Prototype Division cold thrust augmented (CTA) fighter design study. The work performed as an In-House exploratory development program under work unit 19900301. The work described in this report was performed by personnel of the Preliminary Design Group of the Advanced Structures Branch, Structures Division from August through December of 1972. All activity was closely coordinated with personnel of the V/STOL Group of the Prototype Division.

The scope of the effort was primarily that of preliminary structural design and analysis to support the configuration trade studies underway in the V/STOL Group. The designs being considered by the V/STOL Group could be divided into two major configuration categories.

The first category can be considered to be all wing mounted CTA pod systems. The initial configuration in this category had the pod located at the wing tip (Fig. 1). A preliminary loads, weight and structural analysis was performed for this configuration. For several reasons, the pod was subsequently moved inboard from the wing tip. Time limitations permitted only a preliminary weight analysis to be performed for the revised pod location.

The second category considered by the V/STOL Group incorporated fuselage mounted CTA systems (Fig. 2 & 3). Since this configuration was

essentially conventional from a structural standpoint, the only analysis performed on this configuration was that of duct design and other systems which were unique to the CTA system. A conventional aluminum airframe was assummed for the remaining structure. The work performed on these configurationsconsisted of a structural analysis of the duct system and an overall airframe weight estimation.

This report is anticipated to be the first of several reports covering the structural aspects of the CTA configuration studies. Work in the area of CTA has been halted temporarily due to a redirection of the work effort of the V/STOL Group of the Prototype Division.

ORIGINAL CONFIGURATION
CTA FIGHTER

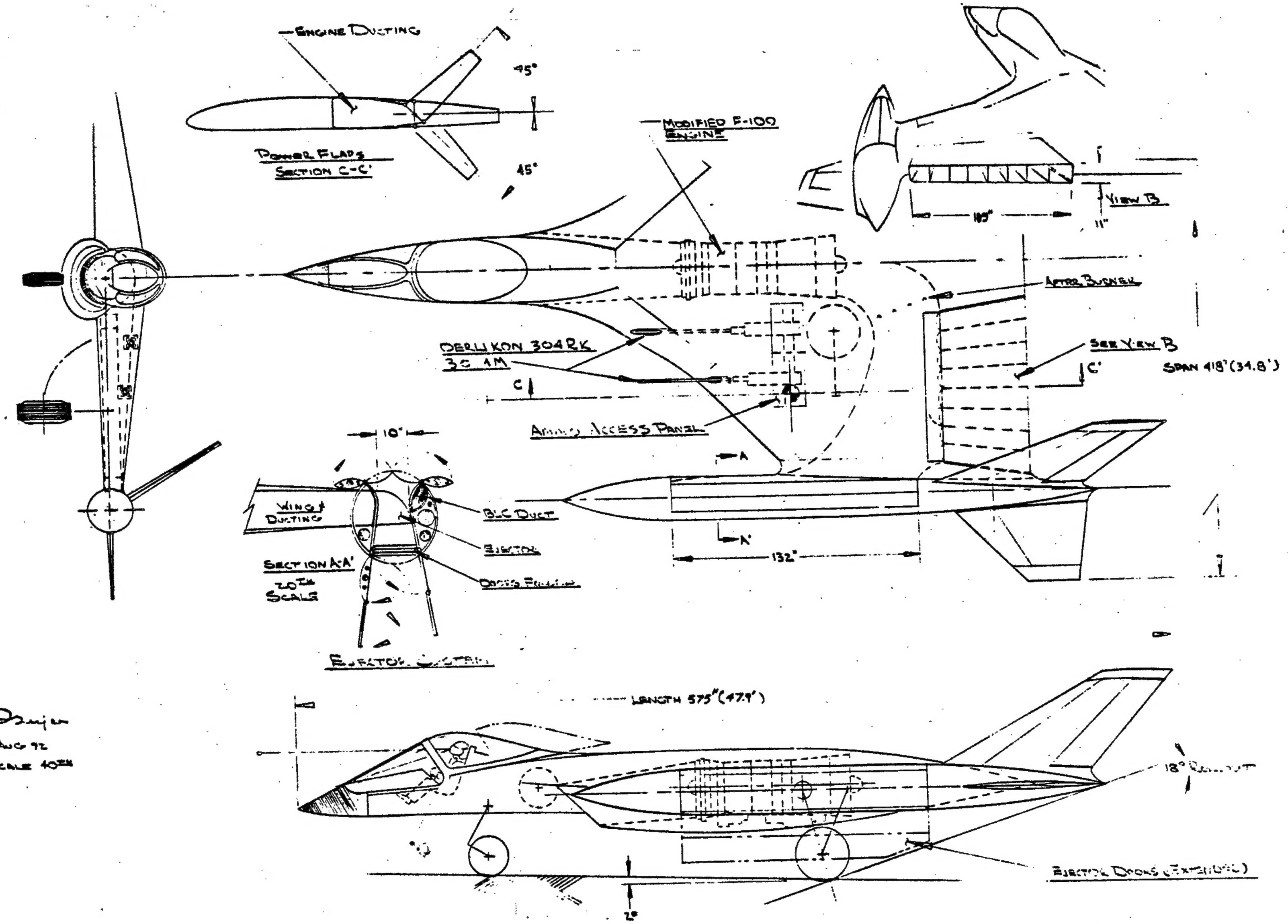
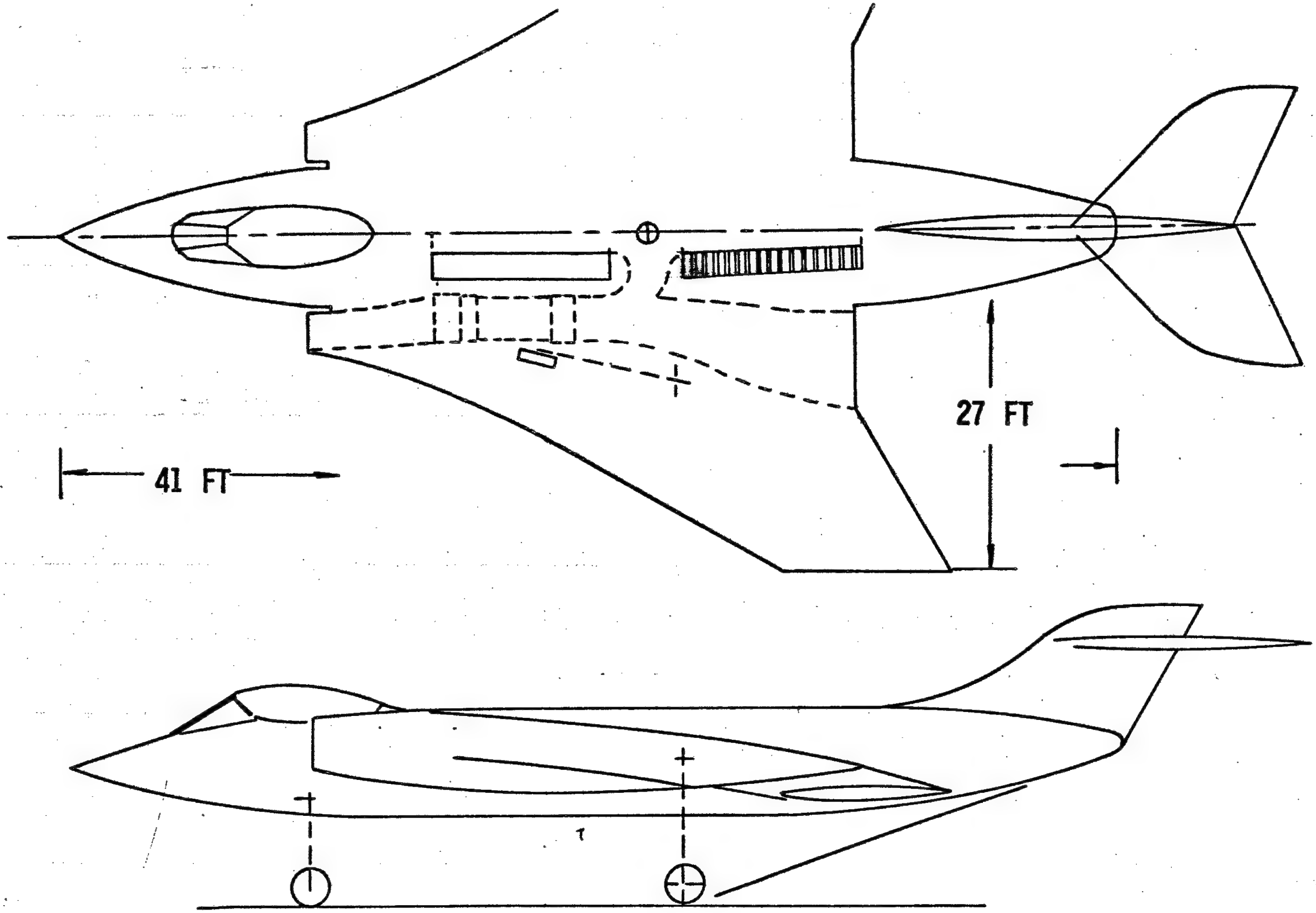


FIG 1

FDL 26-A



FUSELAGE MOUNTED CTA FIGHTER

FIG 2

FUSELAGE MOUNTED CTA NOZZLE SYSTEM

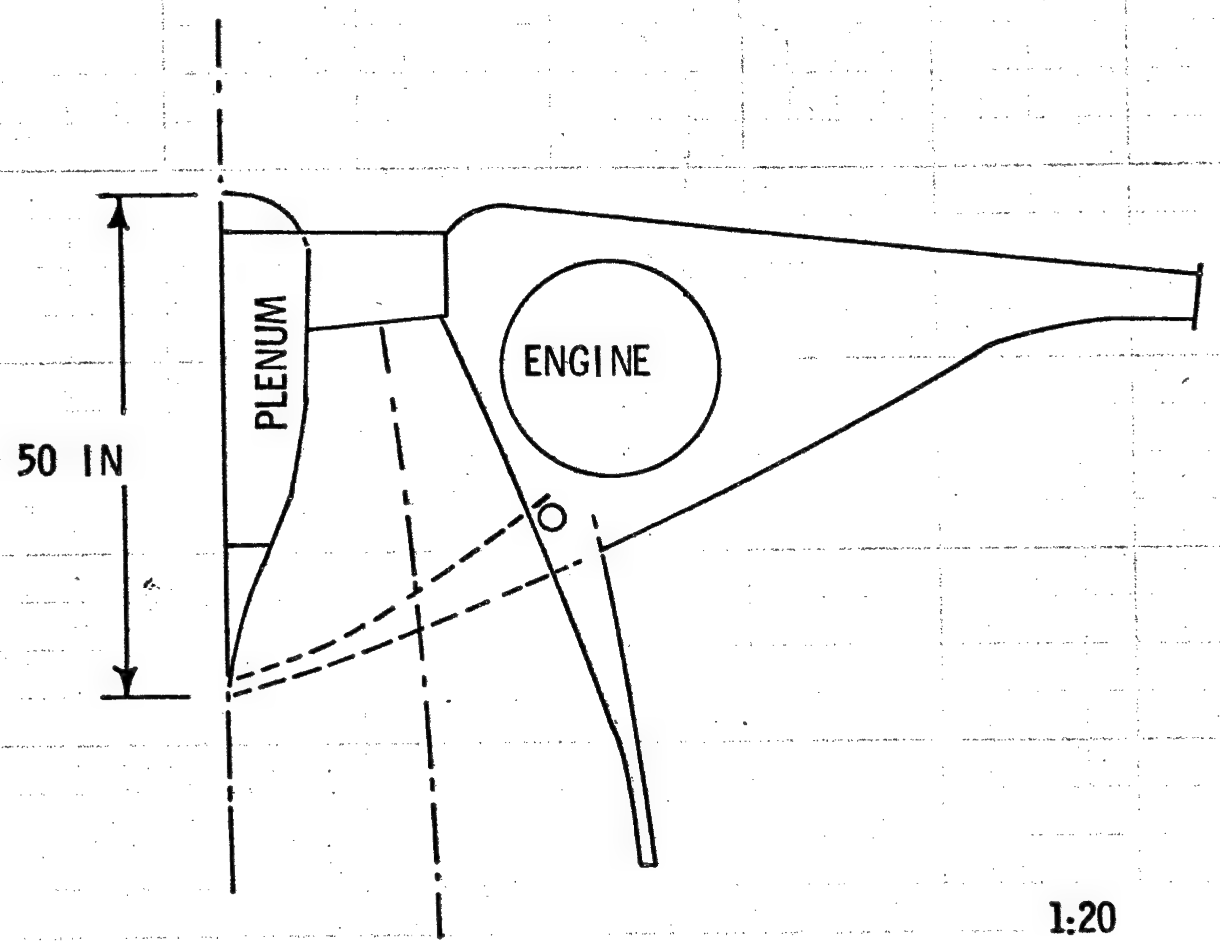


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FIG 3

III. DISCUSSION AND PRELIMINARY RESULTS

A. Wing Mounted CTA Configurations

1. Loads Analysis

Since the loadings on the wing-tip-pod, the horizontal tail, and the vertical tail were some of the main concerns in this preliminary design, a limited loads analysis was performed.

This loads analysis began with an investigation of the aerodynamic loads on the wing-tip-pod only. A set of aerodynamic force coefficients had to first be obtained in order to develop the loads on the pod. At first, it was thought that a comparison with existing aerodynamic data on present aircraft with wing-tip-pods would yield the needed aerodynamic force coefficients.

However, for several reasons, this comparison could not be made. First, the overall size of the pod could not be duplicated on an existing aircraft. Second, the desired speed range presented a limitation since large wing tip pods are not carried on supersonic delta winged aircraft.

Since the location of the pod, type of wing, speed range, and shape of the pod did not lend itself very readily to a comparison with existing aircraft, some relatively detailed calculations would have to be performed to obtain the needed coefficients.

The method selected to calculate these coefficients was taken from NACA RM L53B18. This method would calculate wing-tip-pod coefficients

for subsonic flow. It was felt that by applying several correction methods which are outlined in Reference 2, this subsonic method could be used for a preliminary look at the problem. The corrections outlined in Reference 2, were valid up to approximately M=.9. The coefficients were then extrapolated into the supersonic regime by making use of a few selected wind tunnel data points which were available on similar pods.

As a result of the calculations outlined above, the lift and pitching moment coefficients as a function of angle of attack were obtained. These are presented in Figs. 4 and 5.

Now that the coefficient data was available, a limited loads analysis was performed. Two critical loading conditions were investigated. These two loading conditions included a vertical take-off and a symmetrical pull-up. The vertical take-off condition would induce the greatest thrust load into the wing-pod connection. The symmetrical pull-up condition would produce maximum airload and inertial load on the pod and wing-pod connection.

In order to investigate these two conditions, the wing, horizontal tail, and vertical tail loads had to be calculated. The wing loads were an outgrowth of the calculations performed using NACA RM L53B18. Usually the vertical tail loads would not play a major role in the loads produced by a symmetrical pull-up. However, at this time, the vertical tail was mounted on the pod at a small angle with respect to the vertical. To account for the vertical component of airload on the vertical tail, the area of the horizontal tail was increased. By combining the increase

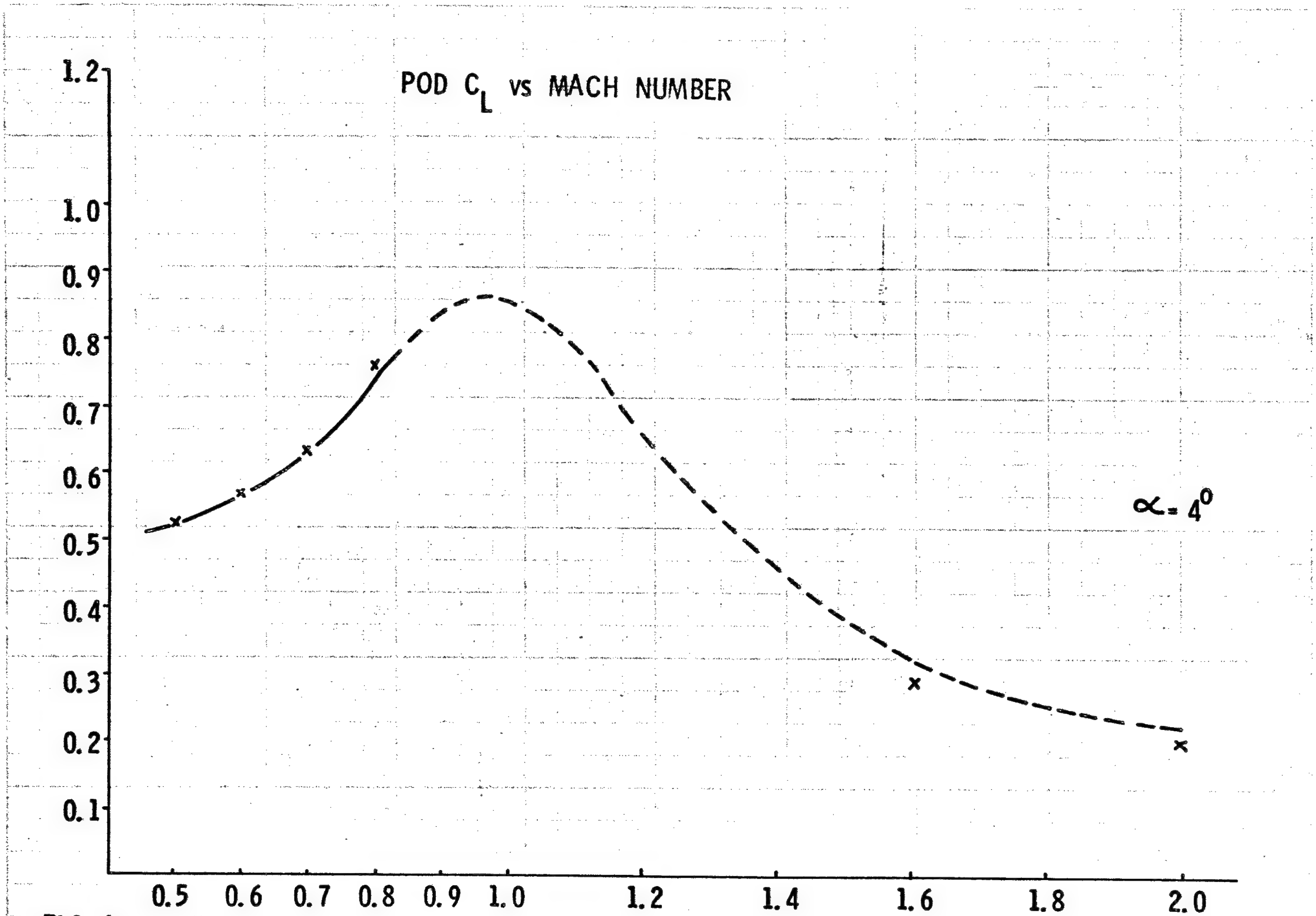

POD C_L vs MACH NUMBER
$\alpha = 4^0$
1.2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0

FIG 4

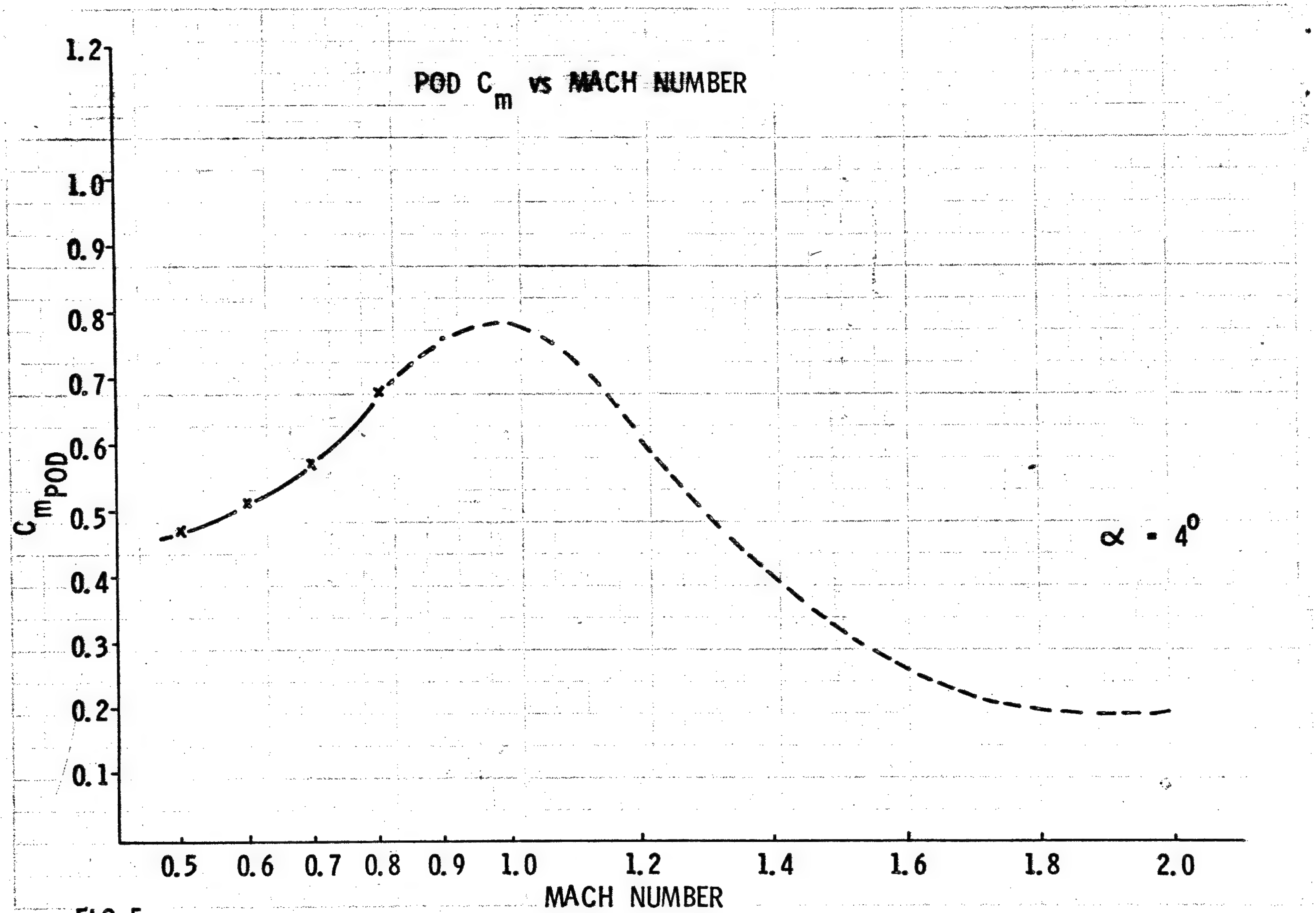

POD C_m vs MACH NUMBER
1.2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
$C_{m_{POD}}$
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
MACH NUMBER
$\alpha = 4^0$

FIG 5

in area of the horizontal tail, the aircraft balancing tail loads, and published preliminary design horizontal tail loads (Ref. 4) a total tail load was developed. All the calculated loads were then combined to produce the total load on the pod.

2. Structural Design

The structural investigation began with the determination of the mass flow requirements and nozzle area ratios. The pod size was optimized and BOXSIZ, a weight estimation program, was run to determine the center of gravity location. Once the center of gravity was determined, the CTA pod thrust and the maneuvering flap thrust were used to balance the aircraft in the VTOL mode. The maneuvering flap travel limits were then developed for vertical lift, forward thrust and afterburner thrust.

The delta wing airfoil data was obtained from the V/STOL Group and cross section layouts prepared at several spanwise locations. The external loads were then applied to the pod so that the outboard portion of the wing could be investigated from a structural standpoint. Basic wing structure was located and optimum load paths were established within the constraints of the airfoil section, duct area requirements and landing gear area requirements.

The shear flows were calculated in the skin and webs at the wing tip. From these calculations, the cap areas and skin thicknesses were calculated and compared with those needed to withstand buckling. The result of these calculations showed that for the design wing tip airfoil section, there was inadequate cross-sectional area to provide for

the structural material needed and the hot gas mass flow rate required to provide a VTOL capability.

In an attempt to revise the mass flow requirements and the nozzle area ratio so that the duct area could be reduced, it was discovered that the center of pressure of the ejector pod moved too far forward of the wing leading edge. This movement created unacceptable pod inertia loads. It was decided at this time that ejector pods located at the wing tips were totally unsatisfactory from a structural standpoint. Suggestions were made to relocate the pods midway between the fuselage and wing tips.

The revised configuration had the ejector pod centerline located at wing station 80 (Fig. 6). There are several advantages to this second configuration. First, the ducting to the pod was shorter and hence lighter. Second, the resultant of the pod thrust is within the wing planform thus greatly reducing the wing torsional loads. A third advantage results from the fact that a supercritical airfoil could be readily incorporated inboard of the pod which provides adequate area for ducting and structure. Prior to moving the pod inboard the entire wing had a supersonic airfoil. Presently, only the outboard portion of the wing must be supersonic. Finally, since the pod moved inboard, the wing bending moments produced as a result of the pod loads is greatly reduced.

The second configuration also had some disadvantages. First, the outer wing loads must be carried around the ejector pod by ring frames. Second, maintence, modification, or removal of the pod is somewhat more complicated when the pod is inboard of the wing tip.

INTERMEDIATE CONFIGURATION
CTA FIGHTER

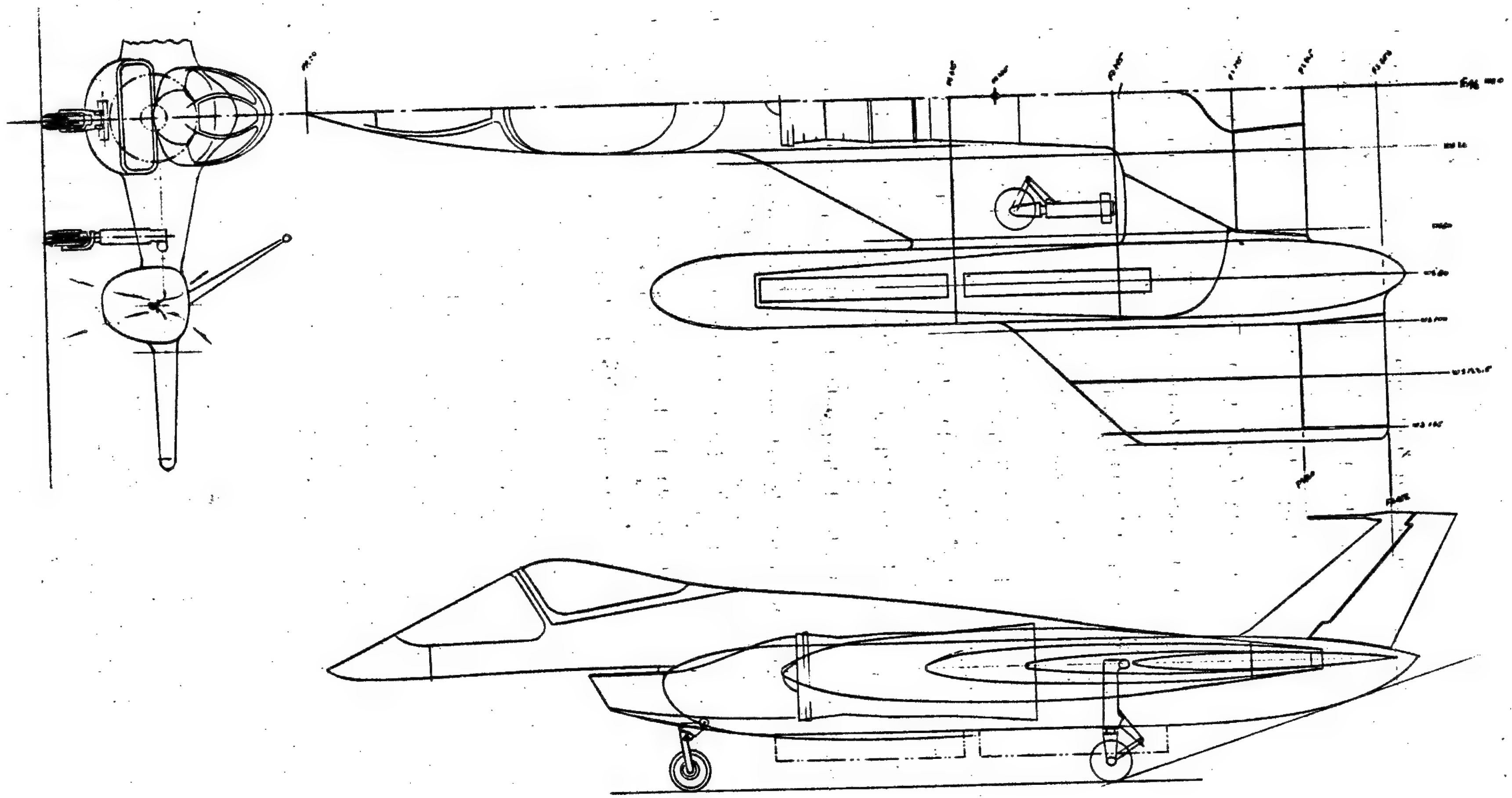


FIG 6

At this point in the study, some wave drag calculations were performed on the second CTA configuration by the V/STOL Group. It was determined that excessive drag would not permit supersonic flight. From this point in time, several design iterations were rapidly performed in an attempt to reduce the wave drag to an acceptable level. At the conclusion of these iterations the resulting design did have a supersonic capability (Fig. 7). The main changes in the design were to increase the fineness ratio of the pods and fuselage and to adopt a conventional tail and bifurcated intake duct.

This final configuration was still under investigation when the work was temporarily halted due to a redirection of the V/STOL Group work effort.

B. Fuselage Mounted CTA Configurations

As discussed previously, work on the centerline hyper-mixing nozzle CTA configuration was primarily concerned with the duct design. The primary emphasis was placed on design, analysis and weight estimation of the ducting system from the engines to the hyper-mixing nozzles.

This ducting design problem was divided into two basic areas. The first area consisted of the main ducting unit from the plenum chamber thru the hyper-mixing nozzles and out of the aircraft. The second area consisted of the ducting from the engine outlet to and including the plenum chamber.

The main problems of both areas were the same. These problems included high operating temperatures combined with internal pressures

FINAL CONFIGURATION CTA FIGHTER
FIRST INTERATION

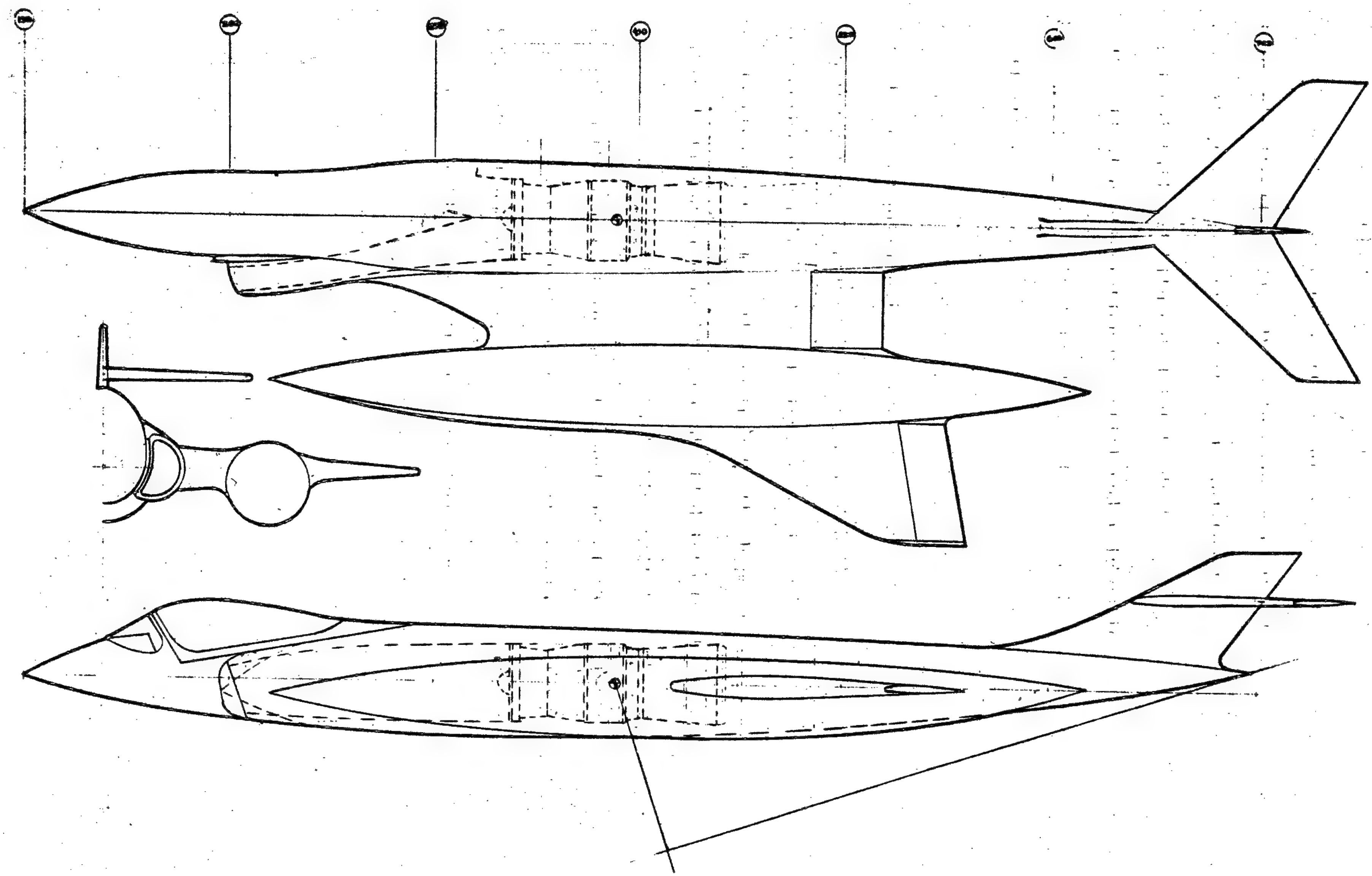


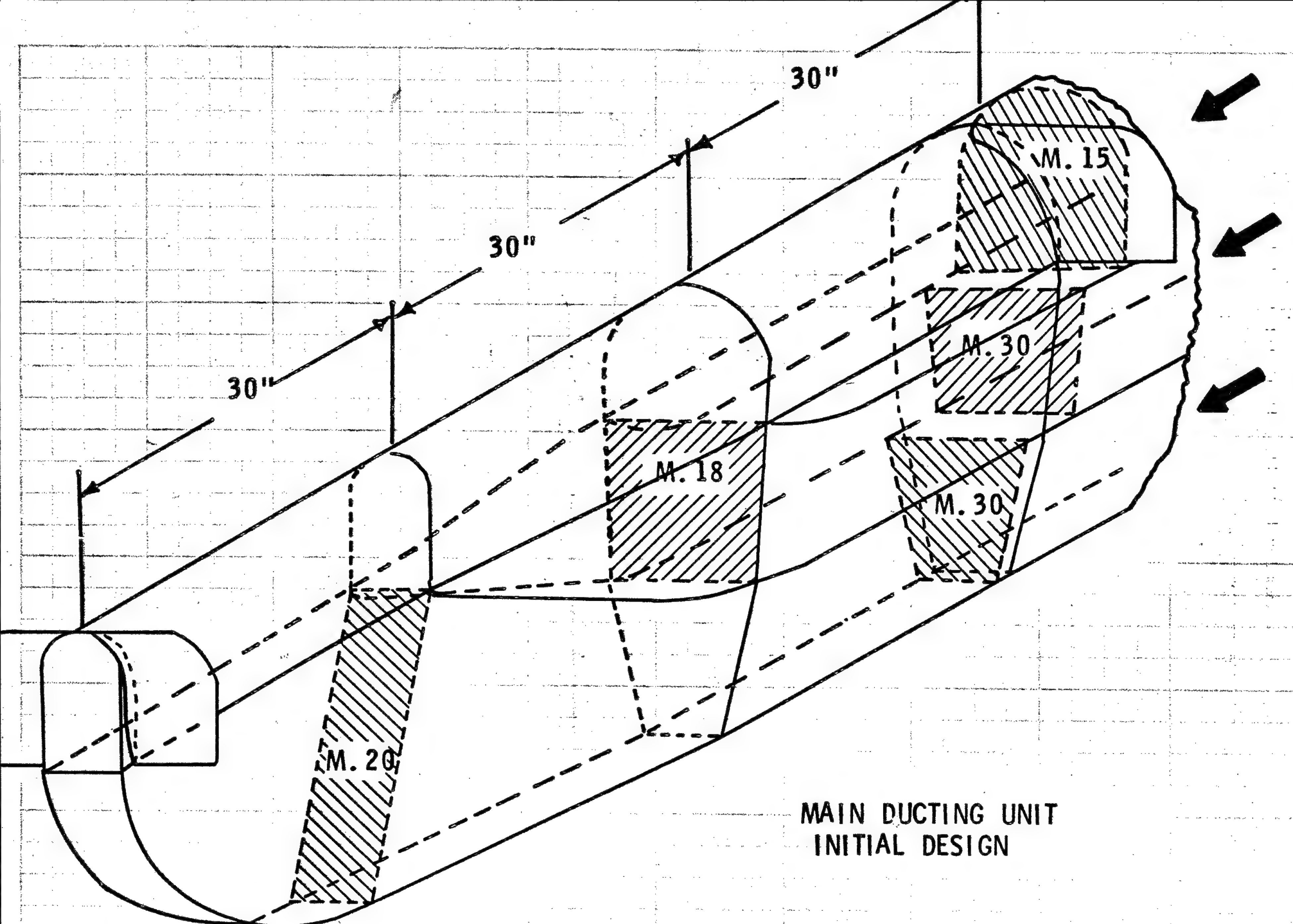
FIG 7

and mass flow requirements which had to be satisfied within the aircraft mold lines.

Numerous design iterations were performed on the main ducting unit. The initial design (Fig. 8) consisted of three rectangular ducts. This design fitted the mold line of the fuselage and had the necessary cross-sectional area to achieve the desired mass flow rate. However, this flat plate design had several disadvantages. The overriding drawback of this system was excessive weight. Since the walls were flat plates, they would have to be very thick or extensively stiffened to withstand the combined pressure and temperature requirements.

The second design concept consisted of circular ducts. As one would expect, the circular duct system functioned very well as a pressure vessel. The required wall thickness of the circular ducts was so thin that the main design consideration switched from temperatures and pressure to material handling and fabrication limitations. The duct walls were designed using minimum gage material. Two possible concepts using circular ducts were investigated. One concept consisted of separate circular ducts for each hyper-mixing nozzle. This concept had three major deficiencies. First, too large a volume was needed for the ducting. Second, the large amount of surface area produced excessive wall friction. The third major deficiency involved the physical turning of the individual tubes. This turning process was much too complicated and required too much space. The second concept involved the use of three circular ducts. This design did not fit in the allotted volume.

The next concept investigated was a combination of circular, elliptical



MAIN DUCTING UNIT
INITIAL DESIGN

FIG 8

and flat plate ducts. As can be seen in Fig. 9 and Fig. 10, this design fit in the allotted volume. Also, the exterior and interior flow lines were exceptionally good with this design. Interior turning of the flow was kept down to 15° and exterior expansion flow was maintained at the optimum angle of 12°. Stresses were calculated at several key locations (Ref. 3). These calculations were the basis for the material thickness and weight estimation. The weight estimation also included an allowance for insulation, fasteners, and a limited amount of back-up structure (provisions for attachment to the primary airframe).

The plenum system was designed following the same approach as was outlined above. The final design (Fig. 11), which consisted of circular ducts and butterfly valves, was briefly analyzed. A weight estimation was made for the complete plenum system.

The final version of the entire duct system had a weight of approximately 2200 lbs. This weight estimation was based on the density and volume of the material used in the duct system plus the addition of a non-optimum factor. A weight penalty in excess of 10% of the aircraft maximum design gross weight due only to the CTA system was considered too costly a price to pay for a system which would only be used in the VTOL stages of flight.

CTA CENTERLINE DUCT SYSTEM

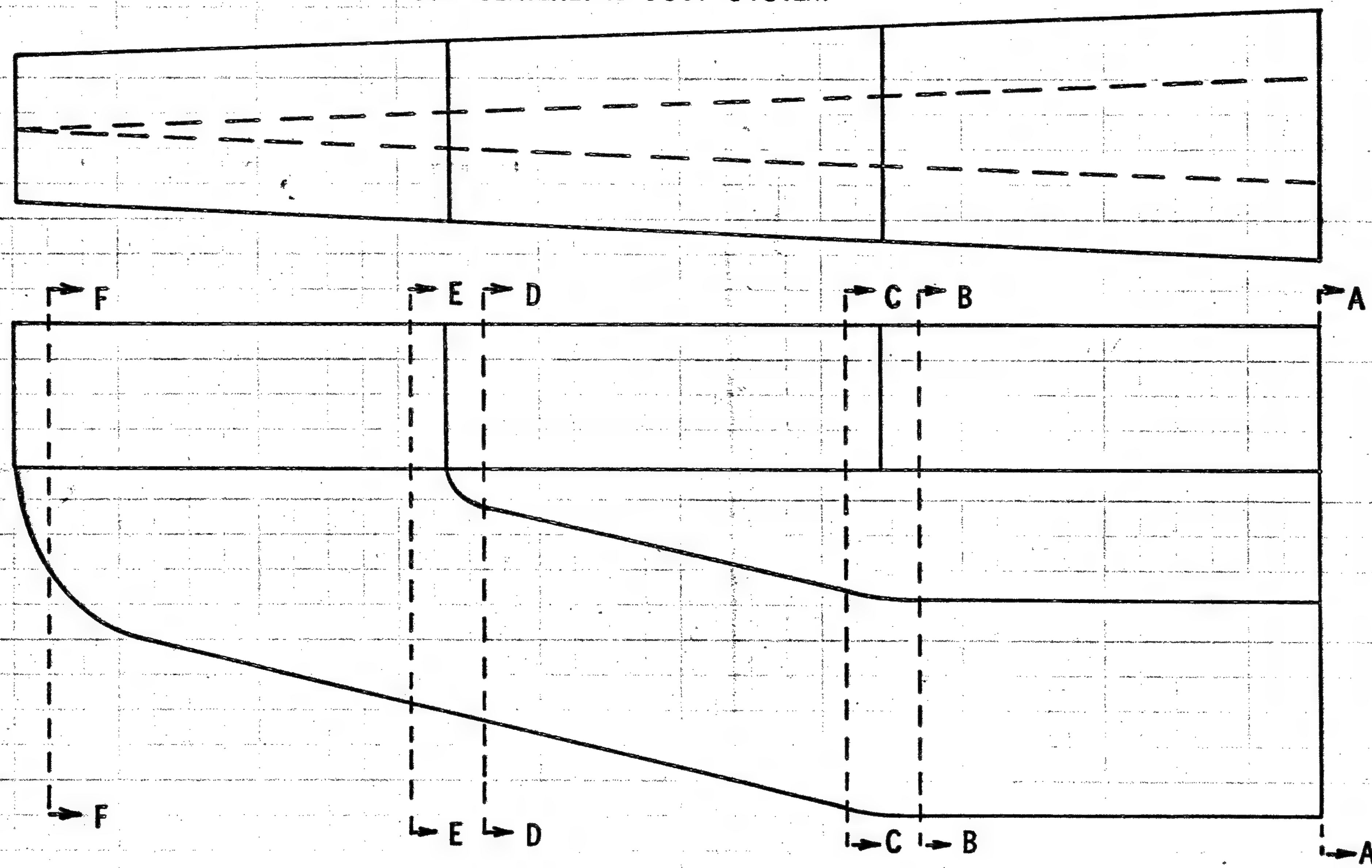
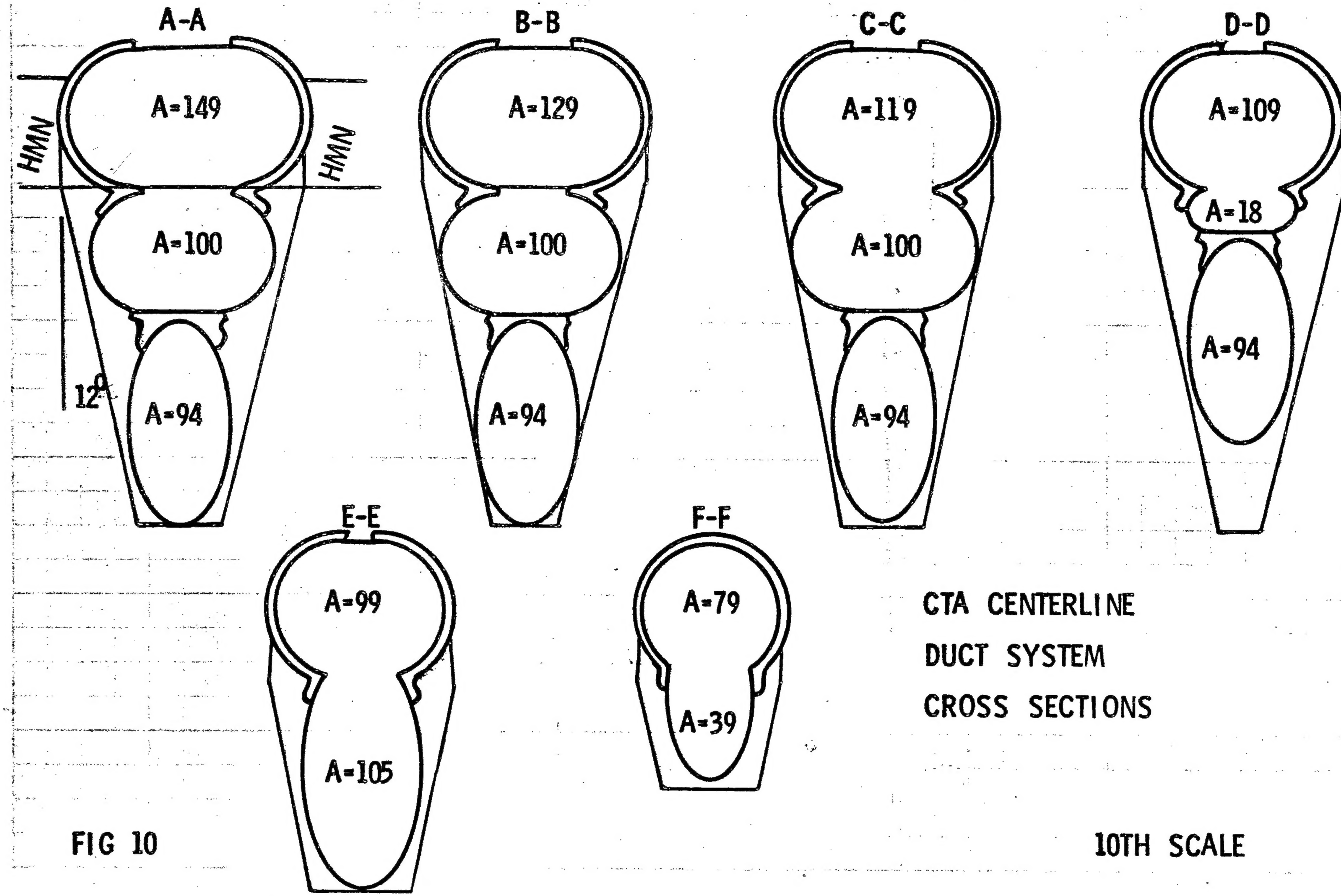


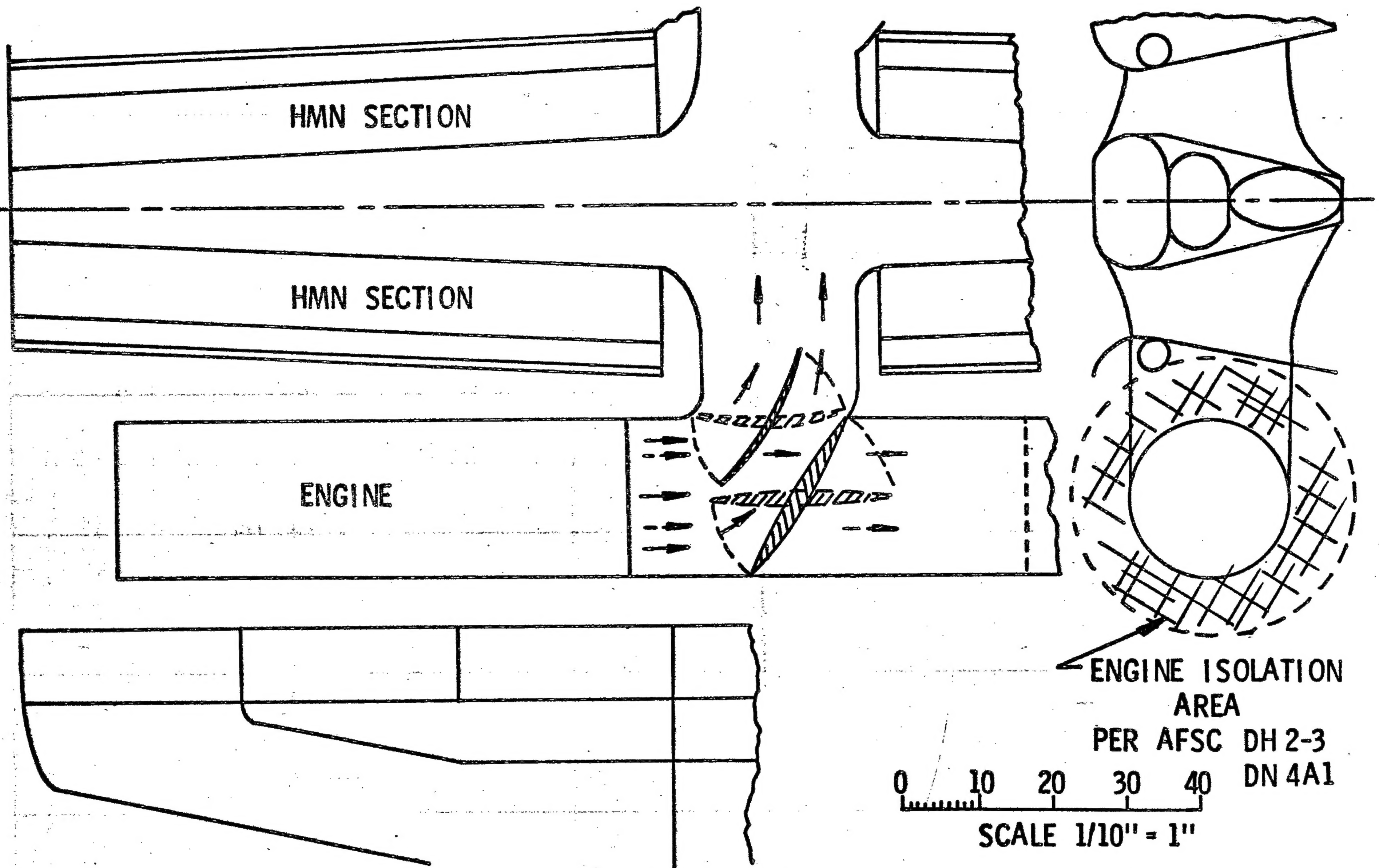
FIG 9



CTA CENTERLINE
DUCT SYSTEM
CROSS SECTIONS

FIG 10

10TH SCALE



CENTERLINE CTA SYSTEM

FIG 11

IV. CONCLUSIONS AND RECOMMENDATIONS

It can be seen from information presented in this report that the structural problems associated with a CTA system can be solved, although in several cases this may involve extensive change to the basic design.

There are however, several recommendations which, if they are feasible and are incorporated in any future designs, can reduce the risk of installing a CTA system on an aircraft. These recommendations are a direct result of the problems uncovered in the investigations presented in this report. These recommendations include:

a) The investigation of using most of the systems needed for the CTA phase of flight for all phases of flight. This would reduce the amount of dead weight and redundant structure which must be carried in the aircraft.

b) Further research on hot duct design. This research should include the effects of both the expansion and contraction of the ducts and possible hot gas leakage from the ducts on the surrounding structure of the aircraft.

c) The investigation of cold air systems which would reduce cost, weight, material restrictions, and design problems.

d) Improving the efficiency of the hyper-mixing nozzles and the associated ducts so that the thrust to weight ratio of the design can be increased.

e) The investigation of other types of power sources for the CTA system.

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